Available online at www.sciencedirect.com
ScienceDirect
Nuclear and Particle Physics Proceedings 273–275 (2016) 934–938
www.elsevier.com/locate/nppp

ATLAS jet trigger performance during run1 and preparation for run2

Sue Cheatham
On behalf of the ATLAS collaboration

Abstract

During run 1 the Large Hadron Collider collided proton beams at the centre-of-mass energy of 7 and 8 TeV, as well as heavy ions at the centre-of-mass energy of 2.76 TeV. The ATLAS trigger is designed to reduce the rate of events from the nominal maximum bunch-crossing rate of 40 MHz to approximately 400 Hz, which is then written on disk offline. The online selection of events containing jets uses a set of jet triggers. The rate from jet events is very high, with a steeply falling spectrum in the distribution of the transverse energy. These jet triggers have been designed to keep an approximately constant jet rate of 0.5 Hz in various transverse momentum intervals and account for around 10% of the total ATLAS trigger rate.

During run 1 the jet trigger was fully efficient at Level 1 for jets with transverse energies above 25 GeV, whilst at Event Filter full efficiency was reached for jets with transverse energies above 60 GeV.

The overall performance of the jet trigger during the 2011 data taking is summarised, together with important updates made during 2012. In addition, the expected performance of the jet trigger in run 2, to start in 2015, is described.

Keywords:
ATLAS, jet trigger, performance, computing, data handling

1. Introduction

The ATLAS jet trigger demonstrated an excellent performance throughout 2011 and 2012 data taking, known as run 1. During run 1, the Large Hadron Collider (LHC) [1] collided proton beams at the centre-of-mass energy of 7–8 TeV, as well as heavy ions at the centre-of-mass energy of 2.76 TeV. The ATLAS trigger is designed to reduce the rate of events from the nominal maximum bunch-crossing rate of 40 MHz to around 400 Hz, which is then written on disk offline. The online selection of events containing jets uses a dedicated set of jet triggers.

Figure 1 shows a 2-jet collision event [2] in ATLAS [3]. Jets are the most prevalent high transverse momentum (p_T) objects produced at the LHC and are an important component of a wide range of physics analyses. As a consequence of collinear divergence, in final states traces of original partons are visible as collimated bunches of energetic hadrons. Various jet reconstruction algorithms are available [4]. Anti-k_t [5] is a sequential recombination algorithm that reconstructs a jet by clustering nearby objects, which is infrared and collinear safe by construction.

Jets are defined as cone-shaped objects in pseudorapidity-azimuthal angle space. The pseudorapidity is defined as $\eta = -\ln\tan\theta/2$, where θ is the polar angle from the beam axis (in the case of massive objects such as jets, the rapidity $y = 1/2\ln[(E + p_Z)/(E - p_Z)]$ is also used). The jet radius parameter R, where $R = \sqrt{(\Delta\eta^2 + \Delta\phi^2)}$, defines the separation of the energy deposits included in the jet reconstruction with respect to the jet axis. The azimuthal angle, ϕ, is measured around the beam axis.

The rate from jet events is very high, with a steeply falling spectrum in the distribution of the transverse energy (E_T). Figure 2 shows the inclusive jet double-

http://dx.doi.org/10.1016/j.nuclphysbps.2015.09.145
2405-6014/© 2016 Published by Elsevier B.V.

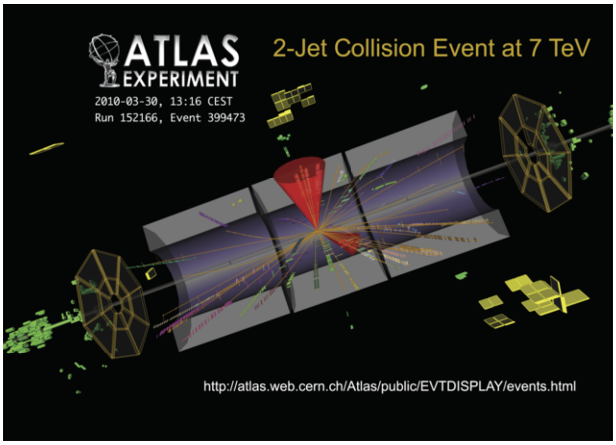


Figure 1: Display of a collision event in ATLAS with two reconstructed jets [2].

differential cross section as a function of jet p_T [6], in different regions of absolute rapidity for jets identified using the anti-k_t algorithm with R=0.4. A trigger that reaches full efficiency close to its E_T threshold, said to have a steep turn-on curve, is therefore important for the jet trigger to manage this huge incoming rate of events.

2. The ATLAS trigger system

The ATLAS trigger system [7] is based on three levels of online event selection:

- Level 1 (L1): jets are identified using L1 calorimeter towers [8] with a sliding window algorithm [9].
- Level 2 (L2): jets are found with a simple cone jet algorithm, seeded by the L1 jets in regions of interest (RoIs). An RoI is defined in (η, ϕ) [10].
- Event Filter (EF): independent of any jets found at L1 or L2 an unseeded anti-k_t jet algorithm is run over topological clusters formed from calorimeter cells [11].
- L2 and EF together are known as the High Level Trigger.

The ATLAS jet trigger naming convention is L1_XJY, L2_XjY and EF_XjY, for the three trigger levels, where X is the jet multiplicity (if larger than one) and Y the trigger E_T threshold.

3. Jet Trigger Performance during run 1

To gain an understanding of the performance of the jet trigger, data was compared to simulation from two

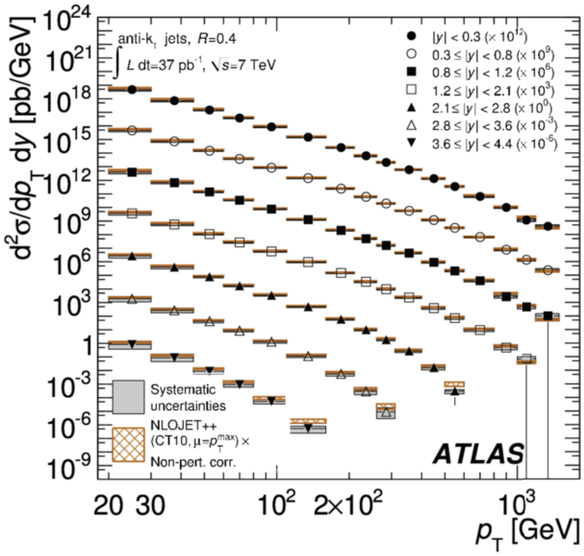


Figure 2: Inclusive jet double-differential cross section as a function of jet p_T in different regions of absolute rapidity for jets identified using the anti-k_t algorithm with R=0.4. For convenience, the cross sections are multiplied by the factors indicated in the legend [6].

Monte Carlo generators (MC), Pythia [12] and Herwig [13]. Each MC generator simulates complete physics events using a hard subprocess with a leading logarithmic parton shower for outgoing hadrons, followed by a soft hadronisation model. Both MC generators include models for the underlying event.

During the 2011 data taking, using the described three level jet triggers, L1 was fully efficient for jets with transverse energies above 50 GeV and EF was fully efficient for jets with transverse energies above 60 GeV. This is shown in the efficiency turn-on curves of Figure 3 [14]. The discrepancies between data and MC are of the order of a few percent. The efficiency turn-on curves at EF are considerably steeper than the corresponding L1 efficiency turn-on curve, due to improved E_T resolution.

Figure 4 shows the E_T resolution as a function of η for jets with p_T>100 GeV and as a function of p_T for jets in the central detector region (0< $|\eta|$ <0.75). Discrepancy is seen between MC and data, particularly in the very central detector region. Agreement also reduces as p_T increases.

The jet triggers account for about 10% of the total ATLAS trigger rate. Figure 5 shows that jets, taus and missing E_T triggers shared about 30% of the total ATLAS trigger rate in 2011 [15].

The jet trigger was designed to keep an approxi-

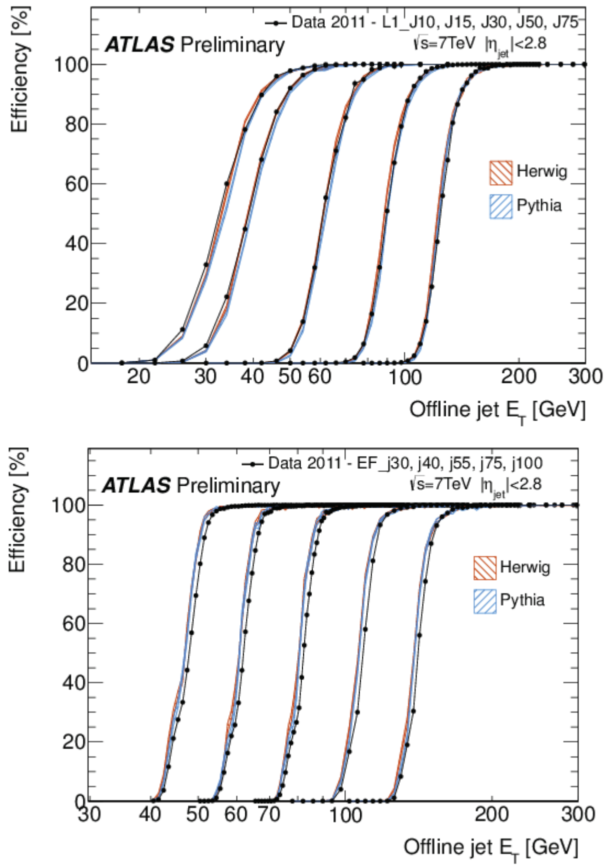


Figure 3: Efficiency turn-on curves for a selection of (top) L1 and (bottom) EF jet triggers in data, Pythia and Herwig MC [14].

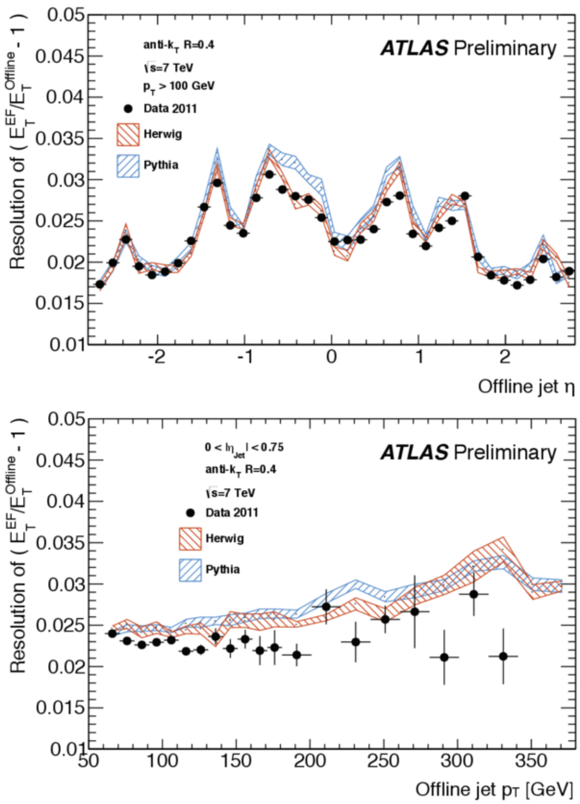


Figure 4: E_T resolution (top) as a function of the jet offline pseudorapidity (η) for jets with offline p_T>100 GeV and (bottom) as a function of jet offline p_T for jets in central region (0< $|\eta|$ <0.75) in data, Pythia and Herwig MC [14].

mately constant jet event rate of 0.5 Hz in various p_T intervals. To control the rate, jet triggers were run on a fraction of the initial events. This is known as prescaling. The rates shown in Figure 6 [14] are before prescales were applied.

4. Heavy ion jet trigger performance

The ATLAS heavy ion (HI) programme 2011 studied the collisions of lead nuclei (Pb+Pb) at energies with a centre-of-mass energy of 2.76 TeV per nucleon pair. Jets produced in HI collisions can be used as direct probes of the resultant evanescent, hot, dense medium, and as such represent a very important tool for physics studies [16].

The dominant issue for jet measurements in the HI environment is the presence of a large amount of energy coming from additional interactions originating from the same Pb+Pb collision, known as the underlying event (UE). The energy deposited by the UE depends on the collision impact parameter. The UE energy deposits need to be subtracted for each event when reconstructing jets. The most central collisions, with 0-10% centrality, have the largest UE contributions. Whereas the most peripheral collisions, with 60-100% centrality, have the smallest UE contributions.

Dedicated HI triggers are required for this very different environment. The primary HI HLT jet trigger algorithm is anti-k_t R=0.2 with an E_T threshold of 20 GeV, seeded by events identified by the L1 trigger with total E_T>10 GeV.

Figure 7 shows that the primary HI HLT jet trigger reaches full efficiency around 30 GeV. There is very little centrality dependence. The jet position resolution, evaluated with respect to offline anti-k_t R=0.2 jets, also shows very little centrality dependence. These show that the UE subtraction method performs well.

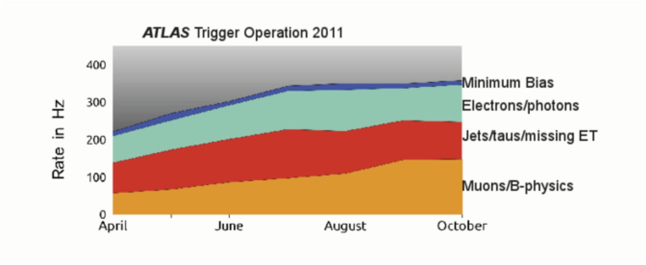


Figure 5: EF stream recording rates, averaged over the periods for which the LHC declared stable beams [15].

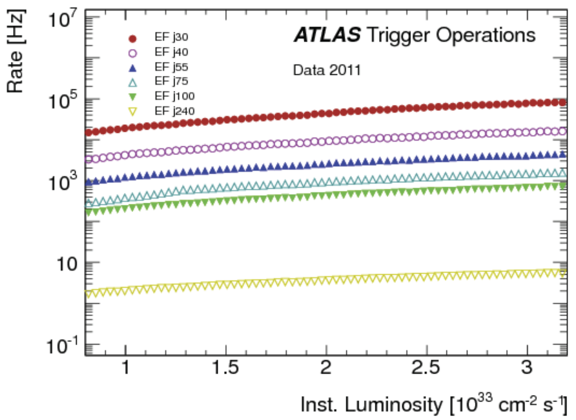


Figure 6: Rates from 2011 7 TeV data for single inclusive jet triggers at EF, where $|\eta_{jet}| < 3.2$ [15].

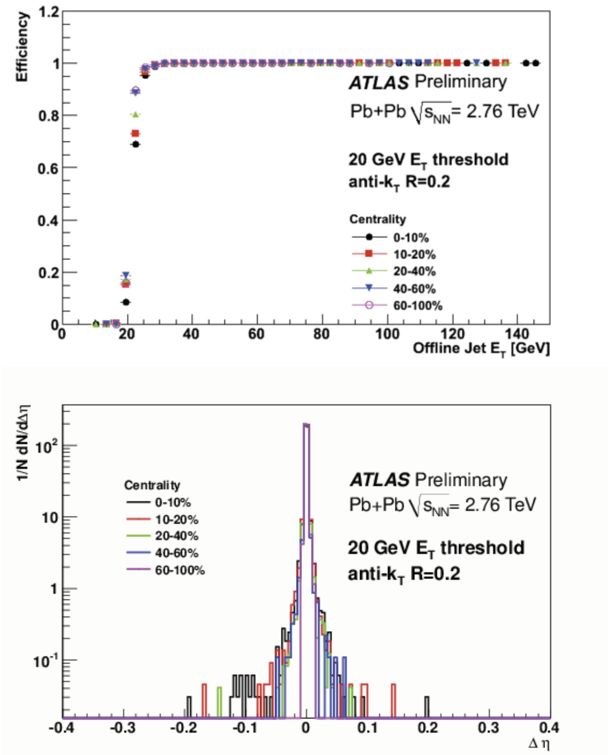


Figure 7: The primary HLT jet trigger for the 2011 HI run used anti-k_t R=0.2; (top) efficiency turn-on curves and (bottom) jet position resolution (in pseudorapidity) [16].

5. Performance improvements during run 1

During run 1 the jet trigger performance was monitored. The original jet trigger design was modified to address specific performance issues. Two such issues are described here.

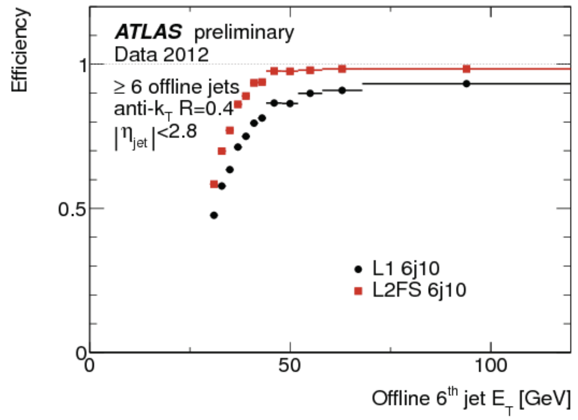
It was noticed that 100% efficiency was not achieved for multijet triggers. This was attributed to the RoI approach being inefficient in a busy multijet environment and due to the fact that the L1 sliding window has a square size (in η, ϕ) while offline jets are circular. A solution was found by running an anti-k_t jet finding algorithm at L2 on coarse-granularity data from the full detector. This is called L2 full scan (L2FS). 100% efficiency was then achieved for multijet triggers as well as the efficiency of the triggers being improved in the turn-on region. This is shown in Figure 8.

The original EF jet triggers were only fully efficient above 60 GeV (as seen in Figure 3) but it was desired to access the low E_T region. A solution was found by running the jet finding algorithm at EF on data from the full detector using only a fraction of the data collected by a random L1 trigger. A random trigger selects events purely at random, as is suggested by its name. The EF is then free from any bias that might be introduced by the jet reconstruction at either the L1 or L2 stages. Full efficiency for jets with transverse energies above 25 GeV was achieved, as shown in Figure 8, which is a considerable E_T reduction. The data shows good performance, even if slightly worse than the MC predictions.

6. ATLAS jet trigger preparations for run 2

In run 2 the jet event rate will increase due to luminosity (by a factor of around 2), centre-of-mass energy (by a factor between 2-4) and the number of simultaneous proton collisions, known as pileup. Strategies are therefore required to keep the trigger thresholds low, restricting triggered rate increase.

The key strategies in preparation for run 2 are: New L1 calorimeter hardware will allow event-by-event pileup subtraction, which is crucial to keep the multijet L1 thresholds low; New topological trigger modules at



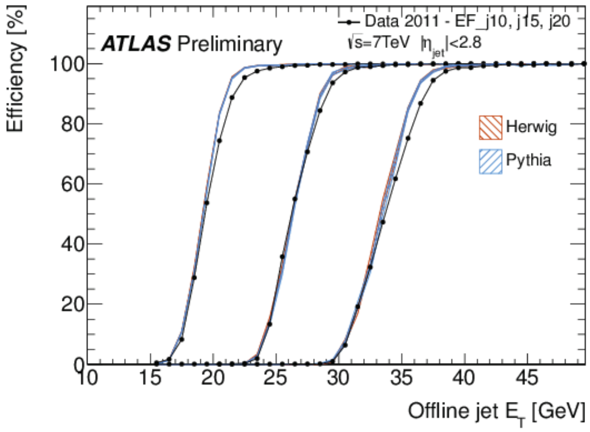


Figure 8: The efficiency turn-on curves (top) for L1 (sliding window) and L2 full scan (anti-$k_t$$R$=0.4) jet triggers in collision events with at least six anti-k_t R=0.4 jets identified offline with $|\eta| < 2.8$ and $E_T >$ 30 GeV. The efficiency is plotted as a function of the sixth offline jet E_T. Efficiency turn-on curves (bottom) for low p_T EF trigger chains in data, Pythia and Herwig MC [14].

L1 will permit angular and mass selections for jet triggers; L2 and EF jet trigger code will be merged, which should result in significant speed improvements, as well as improved trigger efficiency turn-ons and resolutions; New fast tracking at HLT will allow assigning jets to pileup vertices. Studies are ongoing to evaluate the feasibility of full scan HLT, which will obviously have intensive processing requirements.

7. Conclusion

The ATLAS trigger system was designed to cope with the challenging LHC conditions by dividing the trigger into three levels and using a Region of Interest based approach, in which the first level identifies high p_T objects that are verified by the subsequent levels. For the jet triggers, the seeded mechanism introduced performance limitations for very low p_T jets and multijet events. These limitations were overcome by the introduction of full event reconstruction at L2 and also EF. The result is a highly flexible system that can run many different algorithms and configurations, adapting to different requirements of physics analyses and changing data-taking conditions. The ATLAS jet trigger has shown excellent performance since the first collisions of the LHC and has a number of improvements in place for run 2.

References

[1] L. Evans and P. Bryant, 'LHC Machine', JINST **3** (2008) S08001.

[2] http://atlas.web.cern.ch/Atlas/public/EVTDISPLAY/events.html

[3] ATLAS Collaboration, 'The ATLAS Experiment at the CERN Large Hadron Collider', JINST **3** (2008) S08003.

[4] J. E. Huth, N. Wainer, K. Meier, N. Hadley, F. Aversa, M. Greco, P. Chiappetta and J. P. Guillet *et al.*, 'Toward a standardization of jet definitions', In Snowmass 1990, Proceedings, Research directions for the decade 134-136 and Fermilab Batavia - FERMILAB-Conf-90-249 (90/12,rec.Mar.91) 6 p. (105313).

[5] Matteo Cacciari, Gavin P. Salam, Gregory Soyez. 'The anti-k_t jet clustering algorithm', JHEP **0804** (2008) 063 [arXiv:0802.1189 [hep-ph]].

[6] ATLAS Collaboration, 'Measurement of inclusive jet and dijet production in *pp* collisions at $\sqrt{s}$ = 7 TeV using the ATLAS detector', Phys. Rev. D **86** (2012) 014022 [arXiv:1112.6297 [hep-ex]].

[7] ATLAS Collaboration, 'Performance of the ATLAS Trigger System in 2010', Eur. Phys. J. C **72** (2012) 1849 [arXiv:1110.1530 [hep-ex]].

[8] R. Achenbach, P. Adragna, V. Andrei, P. Apostologlou, B. Asman, C. Ay, B. M. Barnett and B. Bauss *et al.*, 'The ATLAS level-1 calorimeter trigger', JINST **3** (2008) P03001.

[9] R. Mehdiyev, Z. V. Metreveli, P. Nevski and D. Salihagic, 'Test of Sliding Window Algorithm fir Jets Reconstruction in ATLAS Hadronic Calorimeters', ATL-CAL-99-002.

[10] R Blair et al, 'The ATLAS High Level Trigger Region of Interest Builder', JINST **3** (2008) P04001 [arXiv:0711.3217 [physics.ins-det]].

[11] ATLAS Collaboration, 'Inputs to Jet Reconstruction and Calibration with the ATLAS Detector Using Proton-Proton Collisions at $\sqrt{s}$ = 900 GeV', ATLAS-CONF-2010-016. https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2010-016/

[12] T. Sjostrand, S. Mrenna and P. Z. Skands, 'PYTHIA 6.4 Physics and Manual', JHEP **0605** (2006) 026 [hep-ph/0603175].

[13] Marchesini, G., Webber, B. R., Abbiendi, G., et al. 'HERWIG 5.1 - a Monte Carlo event generator for simulating hadron emission reactions with interfering gluons', Comput. Phys. Commun. **67** (1992) 465.

[14] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ JetTriggerPublicResults

[15] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ TriggerOperationPublicResults

[16] P. Steinberg, 'Recent Heavy Ion Results with the ATLAS Detector at the LHC', J. Phys. G **38** (2011) 124004 [arXiv:1107.2182 [nucl-ex]].